EFFECTS OF THE STOCKTON SHIP CHANNEL
DEEPENING ON DISSOLVED OXYGEN NEAR THE
PORT OF STOCKTON, CALIFORNIA
(Phase II)

prepared by

Donald J. Smith

Resource Management Associates
3738 Mt. Diablo Blvd., Suite 200
Lafayette, CA   94549

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I. Introduction

This study was done in two phases. Phase I was done during the period 1983-1985 and analyzed project effects superimposed upon the historic years 1974 and 1978. Phase II was done during the period 1986-1988, and analyzed additional historic years. References 1 and 2 are the results of the Phase I study.

Background of Phase I Study

In August, 1983, the Sacramento District of the U.S. Army Corps of Engineers contracted with Resource Management Associates to develop and calibrate a link node hydrodynamic and water quality model capable of evaluating the effect of deepening the Stockton Ship Channel on the dissolved oxygen (DO) resources of the San Joaquin River near Stockton. This project included:

1. Develop a link-node network representation of the Sacramento-San Joaquin Delta System. The network representing the Port of Stockton and Ship Channel was sufficiently detailed to provide good spacial definition of the hydrodynamic and water quality effects of channel deepening with less detail elsewhere.

2. Calibrate and validate the hydrodynamic model under Fall 1974 and 1978 conditions.

3. Evaluate effects of ship channel deepening on the hydraulic characteristics of the Delta channels using the calibrated model.

4. Develop a water quality simulation procedure for the link-node representation of the Sacramento-San Joaquin River Delta system.

5. Calibrate and validate the water quality model to historical dissolved oxygen data, using the 1974 and 1978 test periods.

6. Evaluate the water quality model sensitivity to key input parameters, such as:

   a) inflow quality
   b) depth of light penetration
   c) water column biochemical oxygen demand (BOD)
   d) benthic oxygen demand
   e) phytoplankton and detritus fluctuations
   f) various reaction rate constants

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7. Evaluate the effects of channel deepening by performing water quality simulation for the two test periods using the calibrated model.

8. Estimate the amount of forced aeration required to balance any reduction in DO levels caused by channel deepening.

The results of the Phase I study showed that:

1. The calibrated hydrodynamic model closely predicted both the phasing and amplitude of tidal stage within the study area for both test periods. Reasonable agreement between the computed and the Department of Water Resources (DWR) estimated flows at the Old River-San Joaquin River bifurcation, the Delta cross-channel and Georgiana Slough was also obtained.

2. The calibrated water quality model achieved good agreement between the computed and observed dissolved oxygen levels of the verification periods.

3. The results of the water quality sensitivity analysis showed that phytoplankton growth and respiration and water column BOD and detritus decay were the water quality parameters which had the greatest influence on oxygen concentrations in the ship channel. Both the San Joaquin River and Stockton wastewater facility were major sources of phytoplankton and detritus while the Stockton treatment plant (RWWCF) was the major source of BOD.

4. Deepening the ship channel had virtually no effect on tidal stage or circulation pattern within the Delta. The only hydraulic effect was to reduce current velocities and increase the hydraulic residence time in the ship channel due to the increased channel cross-sectional area.

5. Channel deepening resulted in a slight reduction in oxygen levels within the Ship Channel. The reduction was attributed to decreased net photosynthesis due to a reduced time spent by phytoplankton in the euphotic zone and lower reaeration due to greater depths and reduced channel velocities. The maximum reduction in the oxygen concentration was less than 0.5 mg/l.

Scope of Work of the Phase II Study

The results of the initial study, discussed above, indicated that oxygen levels within the ship channel are dependent to a large extent on the quantity of oxygen-consuming material which enter the ship channel from the San Joaquin River and Stockton wastewater treatment plant. Both the 1974 and 1978 simulation periods had net downstream flows greater than 500 cfs in the San Joaquin River below Old River which resulted in significant amounts of oxygen-consuming materials reaching

the ship channel. The net downstream flow was due to significant San Joaquin River flow at Mossdale, reduced state pumping from Clifton Court forebay during the 1978 period, and the installation of the Old River Barrier during the 1974 period.

During many years net downstream flows are significantly smaller and net upstreams are not uncommon. Since 1978, the Stockton wastewater treatment plant has also been upgraded to provide tertiary treatment and filtration of final effluent. To evaluate project conditions over a longer time period, the effect of reduced net downstream San Joaquin River flows, and present wastewater effluent conditions the following study was undertaken. Other project objectives included further validating the model by simulating other hydrologic periods and evaluating various mitigation measures. For this study, the modeling approach was modified to incorporate the latest evapotranspiration and return flows recently developed by the State Department of Water Resources, and the previously-assumed uniform state water project pumping rate was replaced by the actual Clifton Court gate operation. During this study, the following tasks were performed.

1. Make minor modifications to the link-node network to provide better representation of South Delta hydrodynamics and to allow simulation of revised South Delta Operation schemes proposed by the DWR.

2. Simulate several other periods between 1972 and 1987 to confirm model calibration.

3. Develop a better understanding of the relationship between net San Joaquin River flow and dissolved oxygen levels within the Ship Channel.

4. Determine effects of the deeper Ship Channel on dissolved oxygen for several other periods between 1972 and 1987.

5. Determine the amount of forced aeration required to restore the oxygen deficit created by channel deepening.

6. Evaluate effects of various Delta operation plans on Ship Channel dissolved oxygen.

II. Additional Model Validation

To demonstrate that the model adequately simulates dissolved oxygen under a wide range of hydrologic and wastewater discharge conditions, several Fall periods between 1972 and the present were simulated. For each of these periods, the network shown in Figure II-1 was used. This network incorporated a more detailed South Delta representation to better represent variable Clifton Court withdrawals and proposed flow control structures.

During each period, the measured tide at Antioch was used as the seaward stage boundary. Average daily flows reported in Dayflow Summary (3) were used for the San Joaquin, Sacramento and Mokelumne River inflows and the State Water Project (SWP), Central Valley Project (CVP) and Contra Costa Water District (CCWD) withdrawals. The City of Stockton Regional Wastewater Control Facility (RWWCF) discharges were obtained from the monthly laboratory reports. The flows for all simulation periods are presented in the Appendix. Clifton Court operations were obtained from the states monthly operation report. This report states those times of the day that water was being withdrawn from Delta channels. The Clifton Court inflow rate is then computed based on the differential stage and Clifton Court gate characteristics Agricultural withdrawals and return flow recently quantified by the DWR were input for each node and were interpolated daily based on average monthly data. These flows are computed for each island based on current crop and irrigation patterns and then allocated to the individual nodes based on siphon and pump locations and sizes.

The water quality at Antioch and in the Sacramento and Mokelumne Rivers was based on long term averages and was held constant for all simulations. The assumption of average quality was justified since yearly variations of the parameters of concern are not large and the concentration of oxygen consuming material is low relative to that found in the San Joaquin River and RWWCF effluent. The average San Joaquin River quality was determined for each period from data collected over the years by DWR and the U.S. Bureau of Reclamation (USBR). These data were available on the Environmental Protection Agencies (EPA) STORET system. Agricultural return water quality was based on one set of measurements taken by the DWR during the Spring of 1987. The return water quality data were limited to total organic carbon which was used to set the detritus and phytoplankton concentration in the return flow. The remaining inflow parameters were based on typical agricultural return quality and the San Joaquin River quality which has a large component of return water. The remaining return water quality parameters were set to typical values for the San Joaquin River which contains a large component of return water. The City of Stockton RWWCF laboratory reports were used to determine the average wastewater effluent quality for each simulation period. The inflow water quality data used for each period is summarized in Table II-1. No other waste loads to the Delta were considered.

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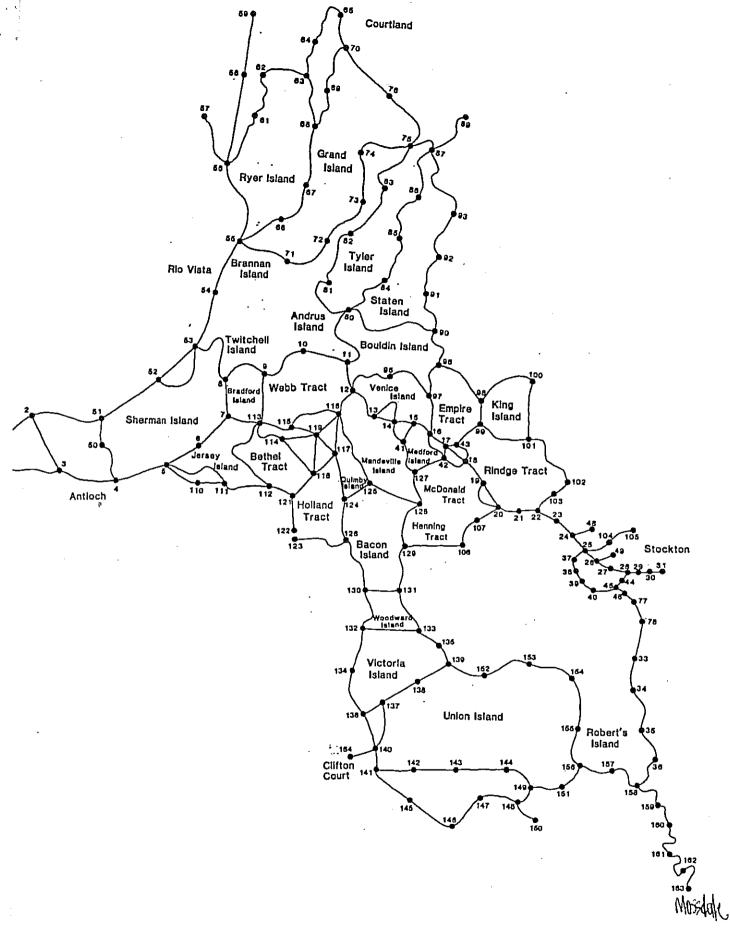
Figure II-1. Link-Node Model Representation of the Delta

Table II-1. Quality of the Tidal Exchange and Major Inflows for
Each Validation Period

Year	Node	TDS (mg/L)	NO3-N (mg/L)	PO4-P (mg/L)	Detritus (mg/L)	5-Day BOD (mg/L)	NH3-N (mg/L)	DO (mg/L)	Temp (°C)	Algae 1 (mg/L)	Algae 2 (mg/L)
Tidal Exchange - Antioch (all periods)											
	1	1000	0.02	0.08	3.0	2.0	0.05	8.0	20	0.35	0.03
Mokelumne River (all periods)											
	89	100	0.26	0.07	3.1	1.5	0.08	8.8	20	0.35	0.03
Sacramento River (all periods)											
	65	100	0.12	0.08	3.1	1.5	0.16	8.8	20	0.31	0.03
Agricultural Returns (all periods)											
		1000	0.60	0.20	15.0	5.0	0.75	8.0	20	0.00	14.00
San Joaquin River at Mossdale											
1972	163	800	0.90	0.12	4.0	3.5	0.62	8.0	23	3.50	0.00
1974	163	800	0.75	0.08	3.0	3.5	0.18	7.5	21	5.00	0.00
1978	163	800	0.60	0.20	4.0	3.5	0.80	8.5	20	3.50	0.00
1979	163	800	0.75	0.12	5.0	3.5	0.20	7.4	19	2.20	0.00
1981	163	800	1.50	0.12	3.2	3.5	0.80	7.9	19	2.80	0.00
1984	163	800	1.30	0.13	4.0	3.5	0.65	8.0	21	3.50	0.00
1985	163	800	1.70	0.14	3.7	3.5	0.41	7.5	21	3.10	0.00
Stockton RWWCF Effluent											
1972	77	935	0.20	0.20	220.0	43.0	11.00	6.0	20	0.00	40.00
1974	77	1000	0.31	0.86	60.0	19.0	11.50	8.0	23	0.00	31.00
1978	77	850	0.26	1.00	80.0	48.0	1.65	7.2	22	0.00	40.00
1979	77	800	0.10	0.38	3.6	6.0	3.00	7.2	20	0.00	3.60
1981	77	890	2.00	0.65	4.5	14.0	8.40	6.0	20	0.00	4.50
1984	77	870	1.10	0.19	3.8	3.0	2.50	6.0	24	0.00	3.90
1985	77	720	1.90	0.09	2.8	5.0	1.30	8.0	23	0.00	2.80

Hourly meteorological conditions for the period 1973 through 1981 were generated from climatological data from the Class "A" station at Stockton's Metropolitan Airport. Following 1981, insufficient data were reported to justify generating hourly data. For 1972 and the years following 1981, the 1973-1981 record was averaged to provide a typical meterological data record at 3 hour intervals for each simulation day. Hydrodynamic model validation was performed using the new network for 1974 and 1978 periods. The tidal stage computed using the new network was essentially same as those computed in the Phase I study. Refer to the Phase I report for a description of the hydrodynamic model calibration.

During the water quality model validation phase, minor adjustments were made to a few of the model parameters reported in the previous study. These adjustments were required to obtain a better fit between the simulation results and observed oxygen levels for the years since 1978. The coefficients used for all simulations are listed in Table II-2. A benthic oxygen demand of 1 g/m²/day was assigned to the Ship Channel since low current velocities may allow accumulation of degradable bottom sediments. As in the Phase I study, zooplankton grazing of algae was not considered. Zooplankton grazing would reduce the phytoplankton concentration, however, oxygen uptake due to zooplankton respiration and decay of zooplankton excrement would not differ greatly from that of the consumed phytoplankton. The effects of zooplankton grazing on the net algae growth rate is reflected in the maximum algae growth rate. The depth of 1% light penetration was held constant at 1.5 meters throughout the Delta for all simulations.

During 1972, 1974, 1979, 1981 and 1984 the Old River closure was in place for all or a portion of these simulation periods. The closure, which is designed to increase net downstream flow in the San Joaquin River past Stockton, was represented in the model by a broad crested weir. The width and elevation of the weir crest was adjusted to obtain the flow split estimated by the DWR. During the quality simulation, small adjustments were made to the computed net downstream flow in the San Joaquin River. These adjustments, which were only a small fraction of the peak intertidal flow, resulted in a net downstream flow equal to those estimated by the DWR for the closure period and equal to those computed using the nomograph to determine "Flow Distribution at Head of Old River" developed by the DWR. These adjustments were made such that the flow continuity within the Delta was maintained.

1972 Validation Period

The period of September 12 through October 15 was selected for the 1972 validation period. This period encompasses both pre- and post-Old River closure conditions. The closure, which was represented as a broad crested weir having a width of 26 feet and a crest elevation of -0.5 feet, was installed near the end of September. During this period, San Joaquin flow at Vernalis ranged between 1540 cfs to 2320 and combined exports averaged approximately 7000 cfs. Prior to the installation of the Old River barrier, the simulated net flows in the San Joaquin River below Old River were near zero. Following installation of the barrier,

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Table II-2. Chemical, Physical and Biological Coefficients

Coefficient	Typical Range (4,5,6)	Calibrated Value
Nitrogen fraction of phytoplankton	.02-.09	0.080
Phosphorus fraction of phytoplankton	.005-.012	0.012
Nitrogen fraction of detritus	.02-.09	0.080
Phosphorus fraction of detritus	.002-.012	0.012
Settling rate for Algae 1, M/day	0-2	0.500
Settling rate for Algae 2, M/day	0-1	0.150
Detritus settling rate, M/day	0-2	0.250
BOD decay rate, 1/day	.1-.3	0.160*
Detritus decay rate, 1/day	.001-0.05	0.050*
Ammonia decay rate, 1/day	.04-0.2	0.080*
Coliform die off rate, 1/day	.5-3.	1.000
Temperature adjustment for BOD decay	1.03-1.06	1.047
Temperature adjustment for ammonia decay	1.02-1.03	1.022
Temperature adjustment for coliform die off	1.03-1.06	1.040
Temperature adjustment for detritus decay	1.02-1.04	1.025
Ratio of oxygen uptake to ammonia decay	4.6	4.600
Ratio of oxygen uptake to detritus decay	1.2-2.0	1.600
Ratio of oxygen production to phytoplankton photosynthesis	1.6	1.600
Ratio of oxygen uptake to phytoplankton respiration	1.6	1.600
Light extinction coeff. for detritus, 1/M x mg/l	.01-.25	0.200
Light extinction coeff. for algae, 1/M x mg/l	.15-.25	0.200
Maximum growth rate for Algae 1, 1/day	1.-3.	2.000
Maximum growth rate for Algae 2, 1/day	1.-4.	2.500
Respiration rate for Algae 1, 1/day	.05-.30	0.150*
Respiration rate for Algae 2, 1/day	.05-.30	0.200*
Light half saturation for Algae 1 growth, kcal/m^2/sec	.002-.004	0.002
Light half saturation for Algae 2 growth, kcal/m^2/sec	.003-.006	0.006
Nitrogen half saturation for Algae 1 growth, mg/l	.03-.10	0.050
Nitrogen half saturation for Algae 2 growth, mg/l	.05-.20	0.200
Phosphorus half saturation for Algae 1 growth, mg/l	.02-.05	0.020
Phosphorus half saturation for Algae 2 growth, mg/l	.03-.06	0.050
Ratio of Chl. a to algal biomass	0.01	0.010
Benthic demand (nodes 11-31), g/m^2/day	0-10	1.000

* Values changed from previous study

the computed flow split between the San Joaquin and Old River was 67% and 33% respectively. These percentages were identical to those estimated by the DWR based on flow measurements made on October 5. The daily predicted flow in the San Joaquin River north of Old River is included in the flow data of the appendix.

The results of the water quality simulation for the 1972 period are shown in Figures II-2 through II-4. Figure II-2 shows computed and observed oxygen profiles at four times during the simulation period. The observed data were reported in the 1972 closure report. Each profile extends from Prisoner Point at river mile 22 (node 11) up the ship channel and San Joaquin River to mile 54 (node 58).

The model predicts the magnitude and location of the oxygen deficit reasonably well considering that mean meteorological conditions were used and that inflow quality was held constant for the entire simulation period.

Figures II-3 and II-4 include time series plots of computed and observed dissolved oxygen concentration at eight locations in the Ship Channel. This figure shows how net downstream flow affects the oxygen concentration at various locations. As the net downstream flow increased due to installation of the barrier, oxygen concentrations decrease at nodes 19 and 21, remain approximately the same at nodes 23 and 24 and increase dramatically above node 26.
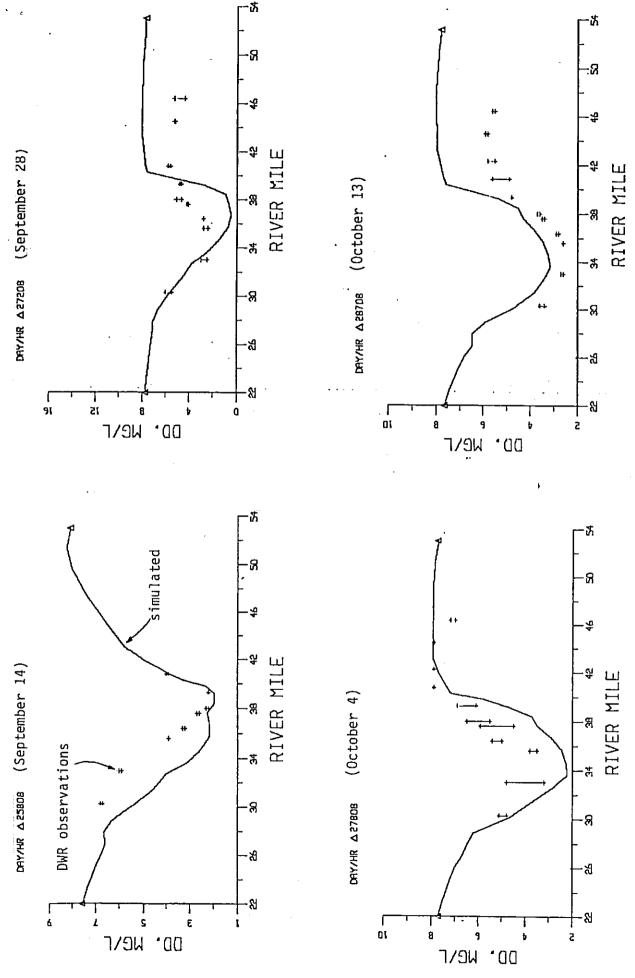
1974 Validation[1] Period

The 1974 simulation period was identical to that used during the initial study. This period was simulated during the present study to confirm that the simulation results were not adversely affected by the new network, revised coefficients, revised agricultural withdrawals and returns, and the method of accounting for the Old River closure. (The closure was represented by increased channel roughness in the initial study and as a broad crested weir in the Phase II study.)

The quality simulation results are shown in Figure II-5. These results show that the model reproduces the location and magnitude of the oxygen sag reasonably well on the two days for which prototype data was available. Failure of the model to predict the magnitude of the deficit probably results from the assumption of uniform inflow quality. The hydrodynamic and water quality results obtained using the revised model are essentially the same as those obtained during the previous study. A more thorough discussion of the simulation results for this period can be found in the Phase I report.

1978 Validation Period

The 1978 simulation period was also identical to that used during the initial study and was simulated to confirm that the simulation results were comparable to those of the initial study.

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Figure II-2. Computed Versus Observed Oxygen Concentration Profiles Along the Stockton Ship Channel and San Joaquin River During 1972

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Figure II-3. Computed Versus Observed Oxygen Concentrations in the Stockton Ship Channel at Nodes 19, 21, 23 and 24 During 1972

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Figure II-4. Computed Versus Observed Oxygen Concentrations in the Stockton Ship Channel and San Joaquin River at Nodes 25, 26, 28 and 77 During 1972

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Figure II-5. Computed Versus Observed Oxygen Concentration Profiles Along the Stockton Ship Channel and San Joaquin River During 1974

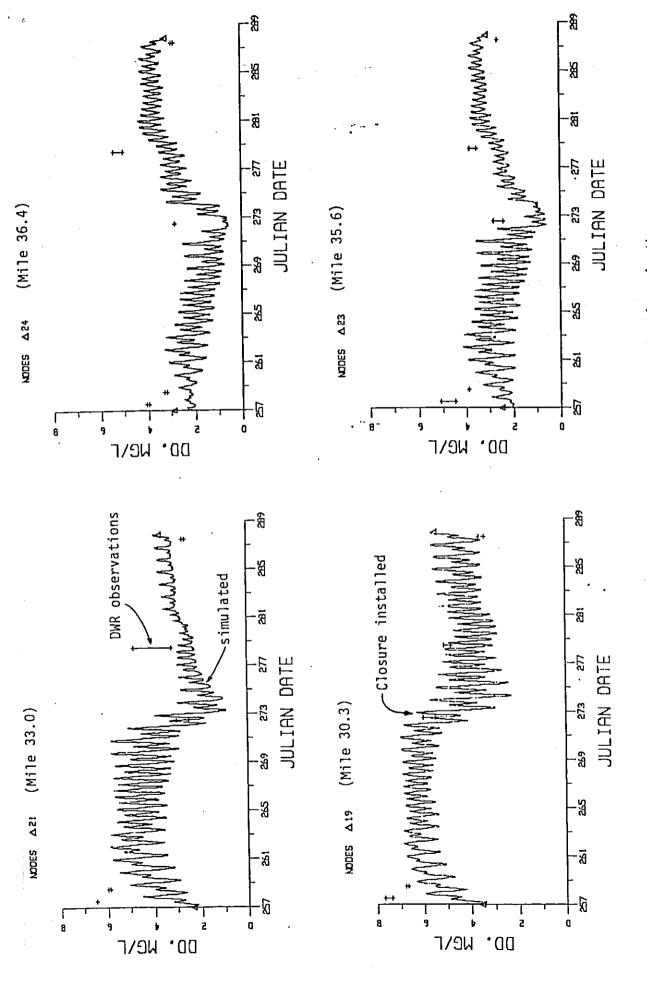The latest quality model simulation results are shown in Figure II-6. These results show that the model reproduces the location and magnitude of the oxygen sag very well throughout the simulation period. These simulation results are similar to the results obtained during the previous study. A detailed comparison of the results achieved during the two studies show that oxygen levels are reduced slightly near river mile 26 in the latest simulation. This reduction is due to the increased detritus concentration in the Sacramento River. A more thorough discussion of the simulation results for this period can be found in the Phase I report.

1979 Validation Period

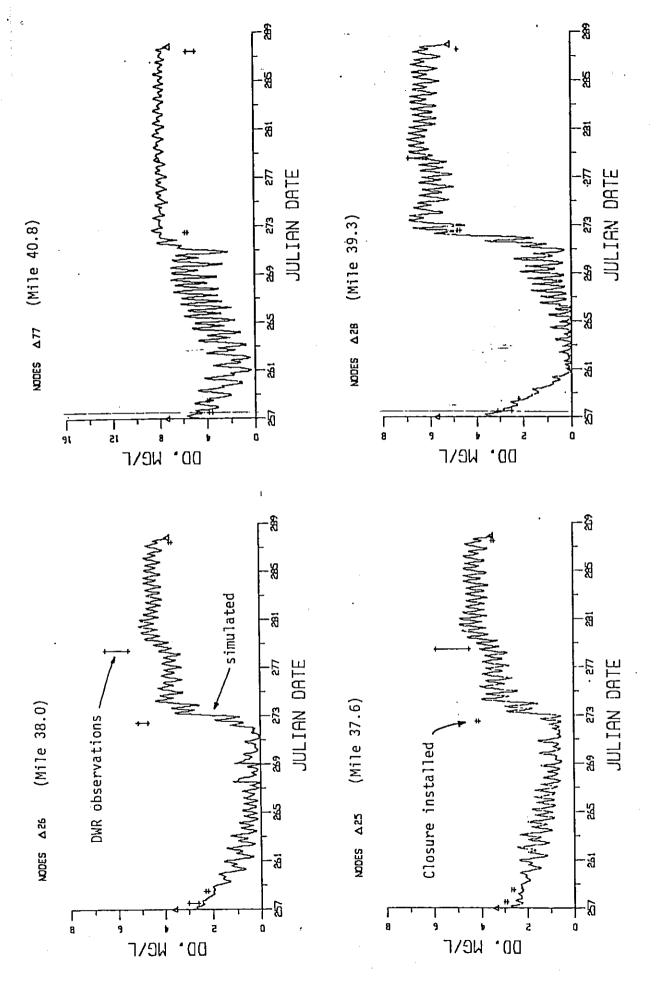The simulation period selected for 1979 extended from September 30 through October 25. The closure, again represented as a broad crested weir having a width of 26 feet and a crest elevation of -1.0 feet, was in place during the entire period. During this period, the San Joaquin River flow at Vernalis generally ranged from 2500 cfs to 3000 cfs except for October 16, 17 and 18, when the maximum flow reached a maximum slightly above 4000 cfs. The SWP, CVP and Contra Costa exports remained fairly constant at approximately 3600, 4000 and 150 cfs respectively.
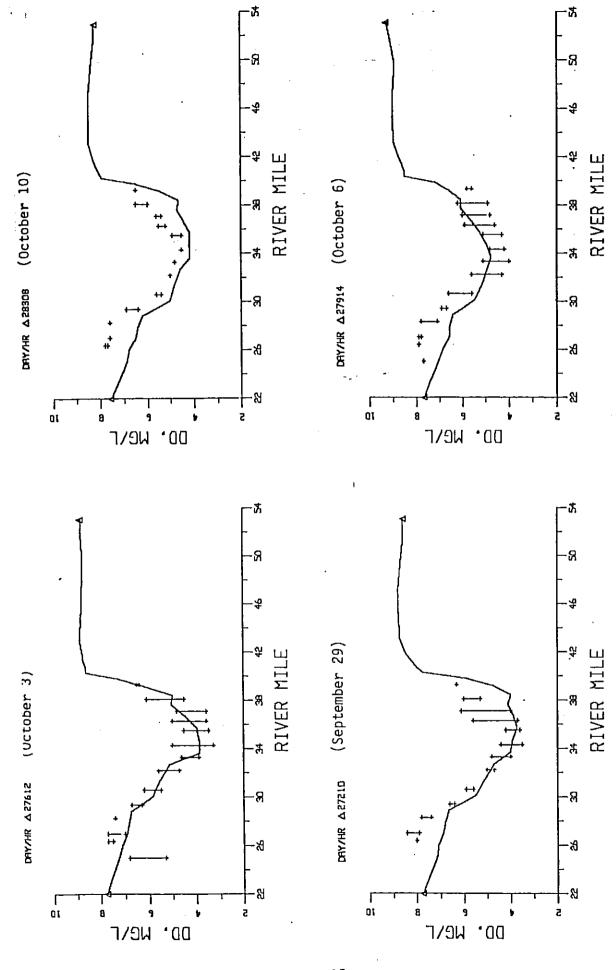
Simulated net downstream flow in the San Joaquin River below Old River ranged between 1250 and 2300 cfs or approximately 60% of the total San Joaquin River flow. This percentage is similar to the 58% estimated by the DWR for October 10, 1979.

The 1979 period was the first simulation period following upgrading of the Stockton wastewater treatment facilities. The decrease in wastewater loadings to the Ship Channel are reflected in the simulation results and observed data presented in Figures II-7 and II-8. These figures show the computed oxygen concentration at six locations along with observed data reported on the RWWCF laboratory reports. Fairly close agreement between the computed and measured oxygen levels was achieved at all locations.
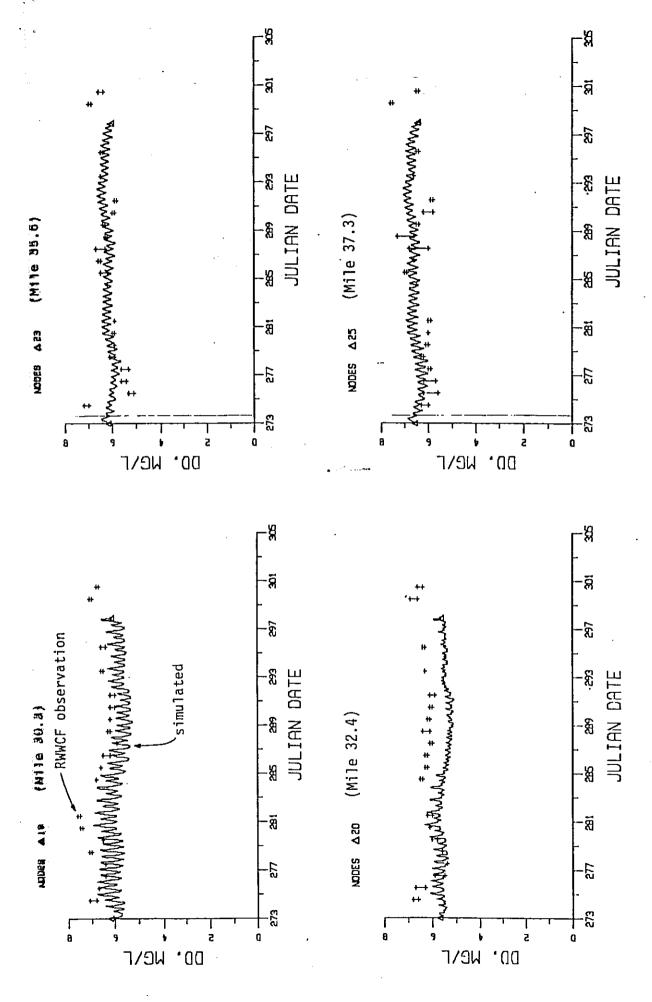
A comparison of these observed and computed oxygen levels with those of the 1972, 1974 and 1978 simulation period shows the impact of the improvements in the RWWCF.

1981 Validation Period

The 1981 period extended from October 1 through October 24 and included both pre and post Old River closure conditions. The closure was completed on October 14 and remained in place past the end of the simulation period. The weir representing the barrier structure had a crest width and elevation of 26 and -0.25 feet respectively. The barrier resulted in a flow split of 66% down the San Joaquin and 34% down Old River. On October 20, the DWR estimated the net downstream flow in the San Joaquin River below Old River during an eight hour period to be 841 cfs or 64% of the total.
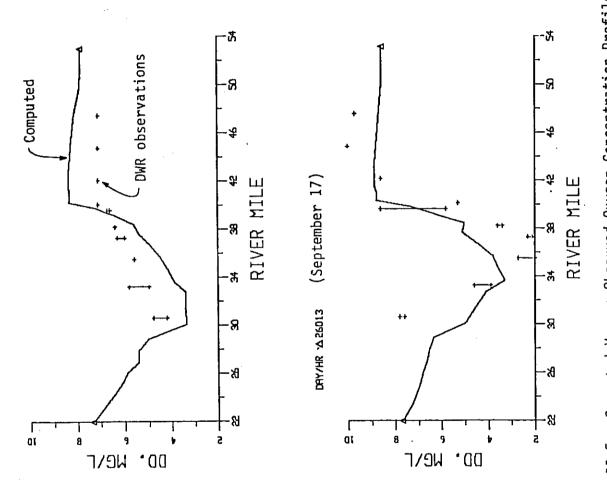
Figure II-6. Computed Versus Observed Oxygen Concentration Profiles Along the Stockton Ship Channel and San Joaquin River During 1978

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Figure II-7. Computed Versus Observed Oxygen Concentrations at Four Locations Within the Ship Channel During 1979

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Figure II-8. Computed Versus Observed Oxygen Concentrations at Two Locations Within the Ship Channel During 1979

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During the simulation period, river inflows and exports remain fairly constant. Total exports averaged approximately 6000 cfs and average Sacramento-San Joaquin River flows were approximately 10000 and 1500 cfs respectively. River flows of this magnitude are lower than those of normal water years.

The results of the quality simulation are presented in Figures II-9 and II-10. These figures show a time history of computed and observed oxygen levels at six locations along the Ship Channel. During the first 10 days of simulation a reasonably good representation of the observed data is achieved. During the final 10 days, however, oxygen levels predicted by the model were substantially below those reported by the RWWCF. Node 19, which is strongly influenced by Sacramento River flow and quality was the only location where a good representation of observed conditions was achieved throughout the simulation. The inability of the model to predict the rise in oxygen levels near the end of the simulation period was likely the result of the assumption of uniform San Joaquin River inflow quality. The average San Joaquin quality used for this period was based on measurements taken on October 5 and 19. On October 19, a chlorophyll a measurement of 9.6 g/l was measured which was approximately 1/2 of that reported for October 5. The significant reduction in chlorophyll a is a strong indication of improving water quality in the river.
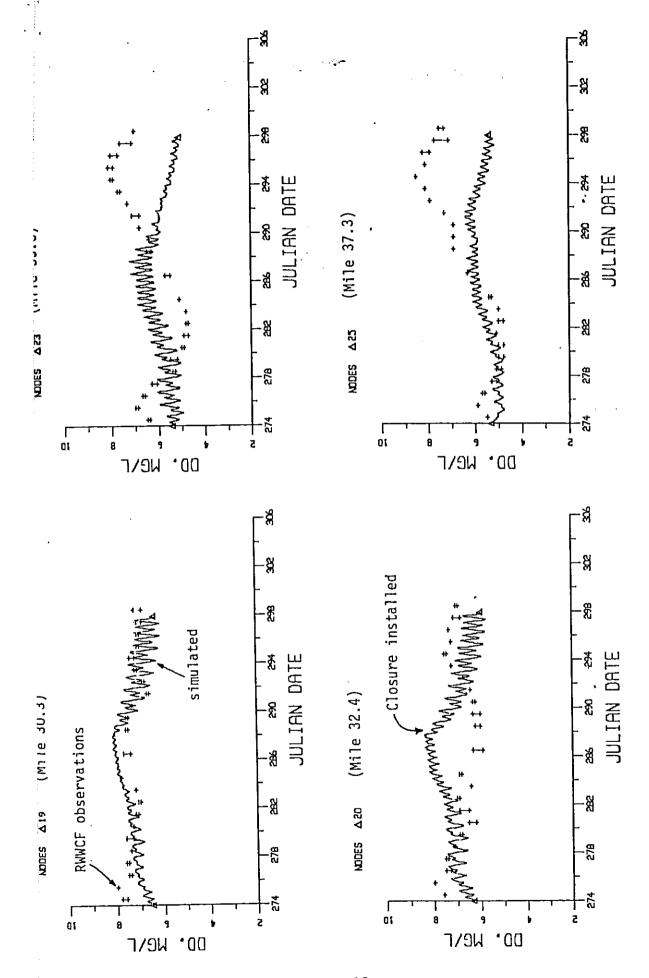
1984 Validation Period

The 1984 simulation period extended from September 1 through October 7 and includes both pre and post Old River closure conditions. The closure completed on September 8 and remained in place through the end of the simulation period. The closure was represented by a broad crested weir having a width of 26 feet and an elevation of -0.2 feet.

· At the beginning of the simulation, the San Joaquin River flow at Vernalis was approximately 2600 cfs. The flow gradually increased and reached a maximum of 4080 by the end of the simulation period. CVP withdrawals averaged near 3800 cfs during the first week of the period and then decreased to approximately 3000 cfs for the remainder of the period. SWP withdrawals were quite variable during this period and ranged from 580 to 3600 with an average of approximately 2000 cfs.

Prior to installation of the Old River closure, the net San Joaquin River flow past Stockton was approximately 400 cfs. Following installation of the closure,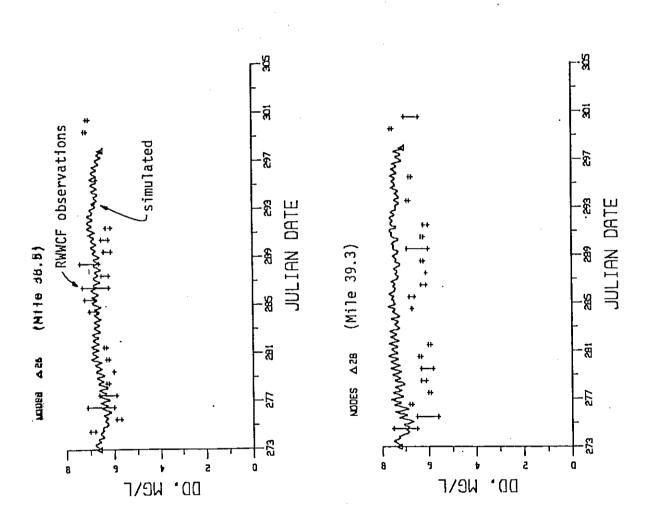 simulated net downstream flow in the San Joaquin River below Old River were approximately 70% of the San Joaquin River flow at Vernalis. This is close to the DWR estimate of 73% which presumably was based on current measurement.

The results of the quality simulation are presented in Figures II-11 through II-13. Figure II-11 shows the computed oxygen levels within the Ship Channel and San Joaquin River along with measured top and bottom oxygen concentrations reported in the 1984 DWR closure report. This figure shows that the model reproduces the location of the sag

Figure II-9. Computed Versus Observed Oxygen Concentrations at Four Locations
on the Ship Channel During 1981

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Figure II-10. Computed Versus Observed Oxygen Concentrations at Two Locations on the Ship Channel During 1981

Figure II-11. Computed Versus Observed Oxygen Concentration Profiles Along the Stockton Ship Channel and San Joaquin River During 1984

Figure II-12. Simulated Versus Observed Oxygen Concentrations
at Four Locations on the Stockton Ship Channel
During 1984

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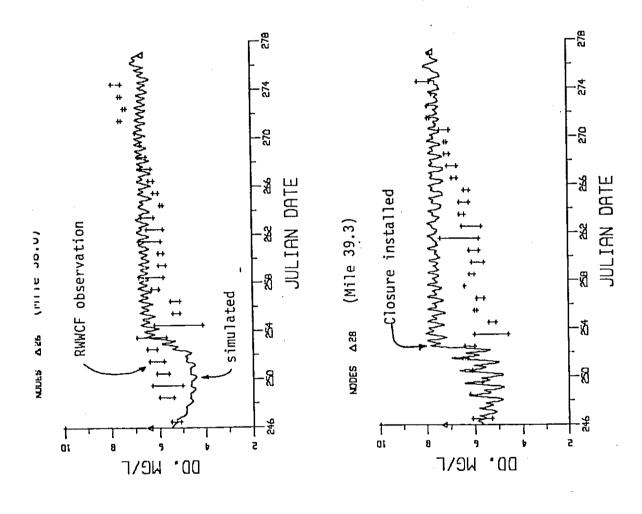
Figure II-13. Computed Versus Observed Oxygen Concentrations Near the Turning Basin During 1984

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fairly well on both dates, however, significantly over-estimates the magnitude on October 6.

Figures II-12 and II-13 show computed and observed oxygen levels at various locations on the Ship Channel during the simulation period. The observation represents top and bottom concentration and were reported on the RWWCF laboratory reports. Reasonably good agreement between the computed and observed oxygen levels were achieved at each location during the simulation. The effects of the Old River closure on computed oxygen levels were the most dramatic near the turning basin (nodes 26 and 28). The observation showed a less dramatic effect which tends to indicate that the model may be overly sensitive to net daily flow. The abrupt change in quality at node 28 may result from underestimating the effects of intertidal flows. The bulk of the data and simulation results show that installation of the Old River closure did little to improve oxygen levels in the Ship Channel during this period.
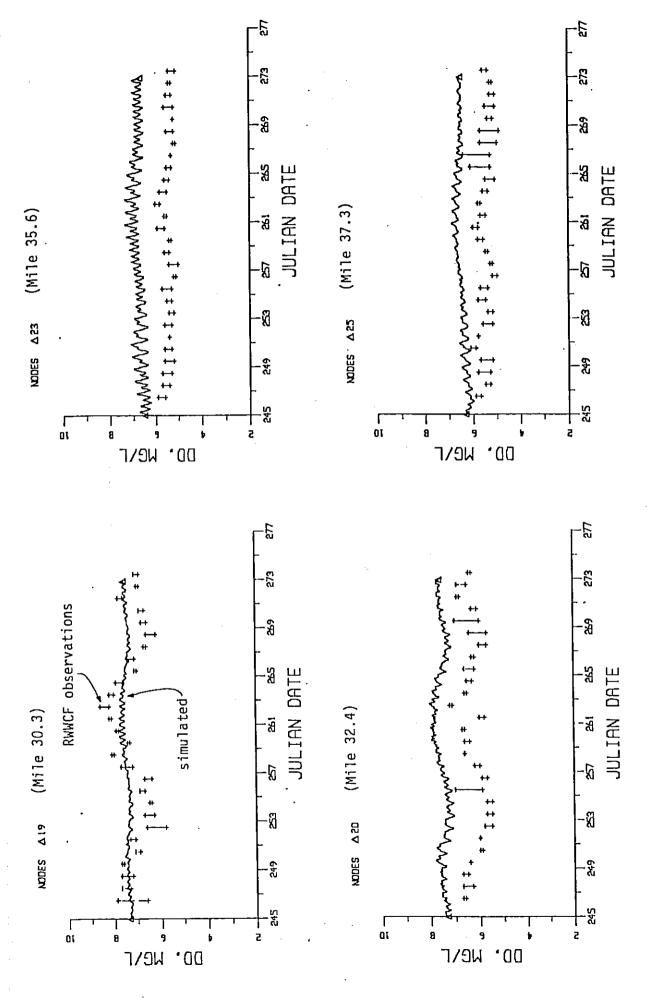
Towards the end of the simulation period, observed oxygen levels were steadily increasing at all locations. This was likely due to better quality water entering the system from the San Joaquin River. The steady increase in observed oxygen levels was not reproduced since constant inflow quality was assumed in the model. The divergence between the computed and observed oxygen levels towards the end of the simulation explains the overestimate of the oxygen sag on October 6 seen on Figure II-11.

1985 Validation Period
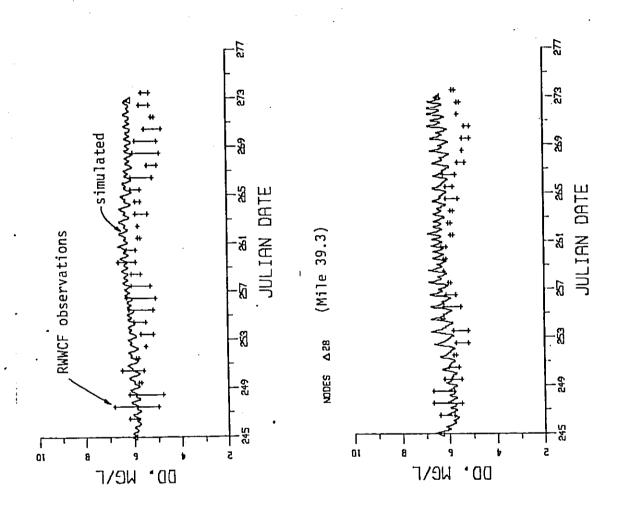
The 1985 simulation period extended from September 2 through September 30. The Old River closure was not installed in 1985 since oxygen levels did not reach critical levels.

During the simulation period, San Joaquin River and Sacramento River inflows remained fairly uniform at approximately 2000 cfs and 11000 cfs respectively. CVP withdrawals were fairly constant and averaged slightly above 4000 cfs. SWP withdrawals were more variable and averaged approximately 5500 cfs for the first half of the month and approximately 3000 for the remainder of the month. During the entire simulation period the computed net flow in the San Joaquin River past Stockton was near zero and never exceeded 200 cfs in either direction.

The results of the quality simulation are presented in Figures II-14 and II-15. These plots show the computed and observed oxygen concentrations at six locations along the Ship Channel. The simulated oxygen levels match the observations reasonably well at nodes 19, 26 and 28. At node 19, the water quality appears to be dominated by Sacramento River water which flow upstream in the San Joaquin River and south through Turner Cut. At nodes 26 and 28, the water quality appears to be controlled by oxygen consuming materials entering the turning basin with the intertidal flows from the San Joaquin River. Between the turning basin and Turner Cut, no oxygen consuming loads, other than a small quantity of agricultural return flows, are considered in the model. As the simulation progresses, relatively small quantities of oxygen consum-
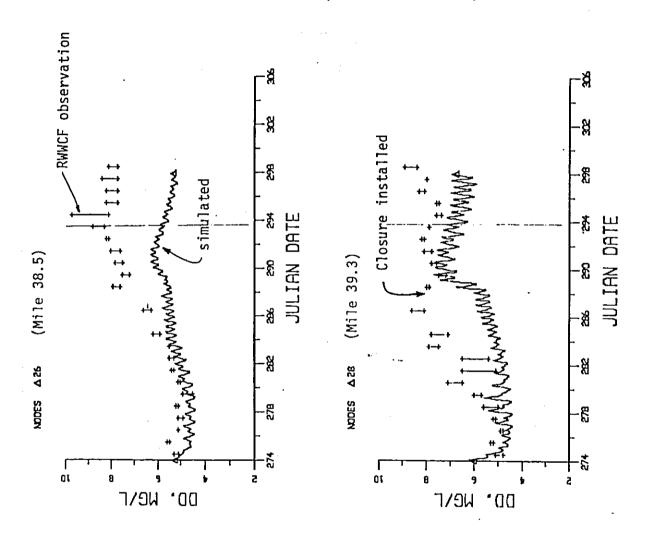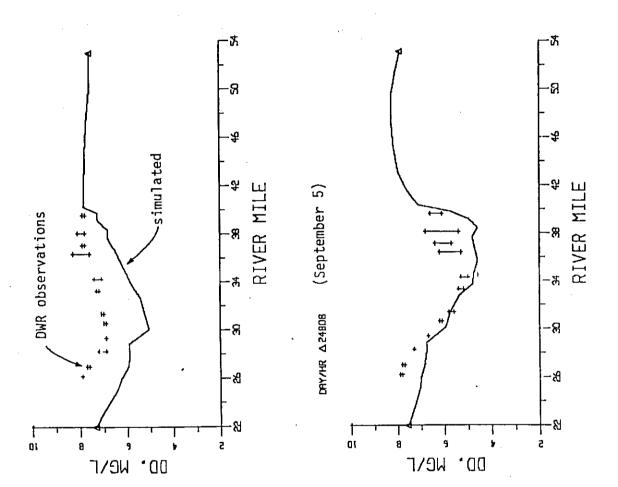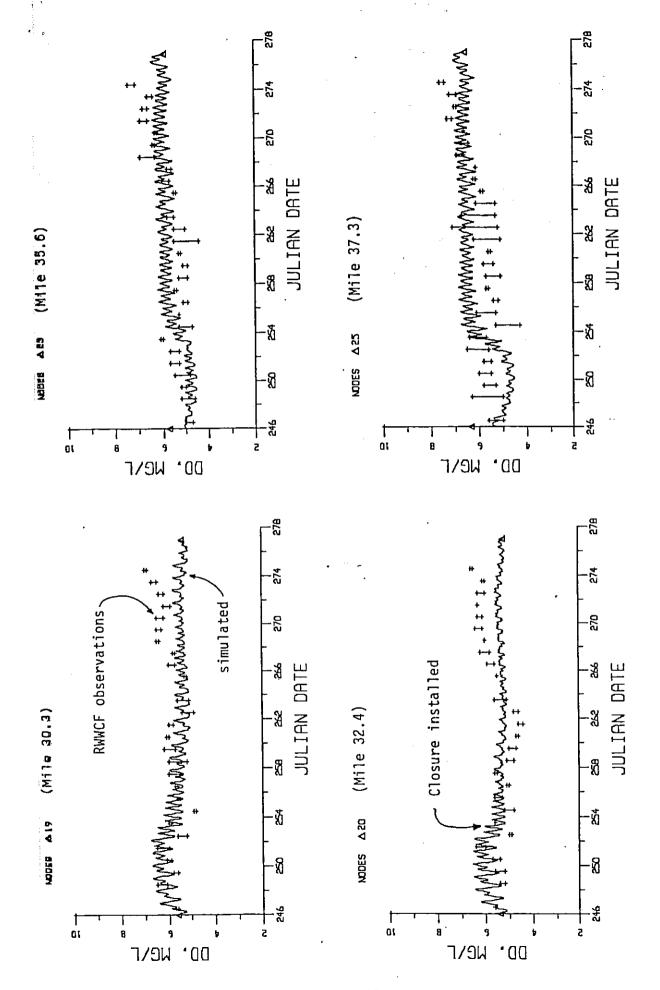
Figure II-14. Computed Versus Observed Oxygen Concentrations at Four Locations Within the Ship Channel During 1985

Figure II-15. Computed Versus Observed Oxygen Concentrations at Two Locations Near the Turning Basin During 1985

ing materials enter this portion of the Ship Channel with the intertidal flows resulting in higher than observed oxygen levels. These results would suggest that the intertidal transport may be underestimated in this portion of the channel or additional sources of oxygen consuming materials exist in this area. During most years when net flows are larger, any local inflows would represent a much lower fraction of the total oxygen consuming loads which enter the ship channel.

III. Effects of Ship Channel Deepening and Mitigation Measures
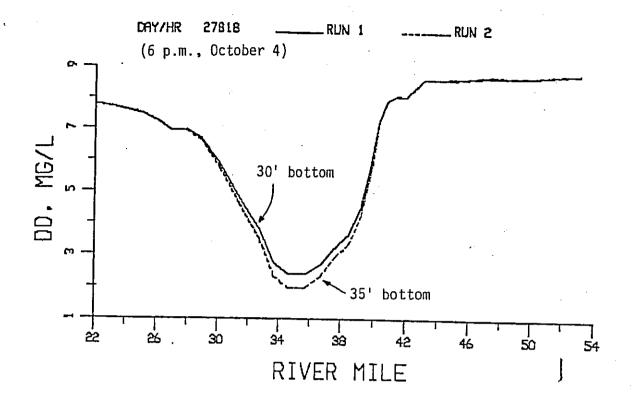
In the previous study, it was determined that channel deepening had essentially no effect on tidal stage or phasing nor on channel flow rates and inter-Delta circulation. Channel velocities, however, were reduced inversely proportional to the increase in cross section area since total flow remained the same. The reduced velocities coupled with increased depth resulted in a decrease in the computed reaeration of up to 20%. The hydraulic effects of channel deepening were comparable for the additional years simulated during this project.

The water quality analysis performed for 1974 and 1978 during the Phase I project indicated that a channel bottom elevation of 35 feet would result in a maximum reduction in dissolved oxygen of approximately 0.25 mg/l when compared with results assuming existing channel geometry. The previously authorized channel depth was 30 feet. When the computed oxygen concentration assuming a 30 foot bottom elevation was compared with the results for a 35 foot bottom, a maximum reduction of approximately 0.5 mg/l was computed.

During the present study each simulation period described in Chapter II was simulated assuming both a 30 foot and 35 foot bottom elevation. In each case, the maximum computed oxygen deficit resulting from increasing the depth from 30 to 35 feet was approximately twice the increase resulting from deepening the channel to 35 feet from existing channel conditions.

The simulation results presented in Figures III-1 through III-4 show computed oxygen concentration for a 30 and 35 foot bottom elevation in a typical day during the 1972, 1978, 1979 and 1985 simulation periods. Results for 6 a.m. and 6 p.m. are plotted to show diurnal effects. The 1972 and 1978 periods were selected to show the effects of deepening under high oxygen consuming loads (pre RWWCF upgrade). The 1972 condition shown in Figure III-1 is towards the end of the simulation period when a significant net downstream flow in the San Joaquin prevailed. Figure III-2 shows the results for 1978 when net downstream San Joaquin River flow was approximately half that of the 1972 period. These two figures show that the maximum oxygen reduction was slightly less than 0.5 mg/l under both flow conditions.

A similar rationale was used for selecting 1979 and 1985 for demonstrating the effects of channel deepening. Both of these periods represent lower oxygen loadings (post RWWCF upgrade) condition, however, net flow conditions were dramatically different. Figures III-3 and III-4 show computed oxygen concentration profiles for 30 and 35 foot bottom elevations on October 22, 1979 and September 17, 1985, when net downstream San Joaquin River flows equal approximately 1700 cfs and 50 cfs respectively. The different net downstream flows result in significant different placement of the point of minimum oxygen concentration, however, the computed oxygen deficit due to channel
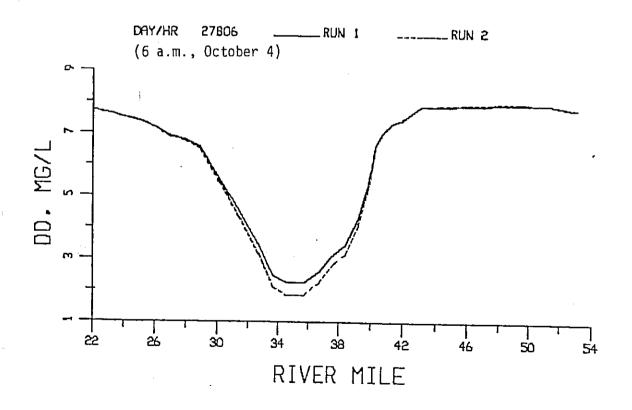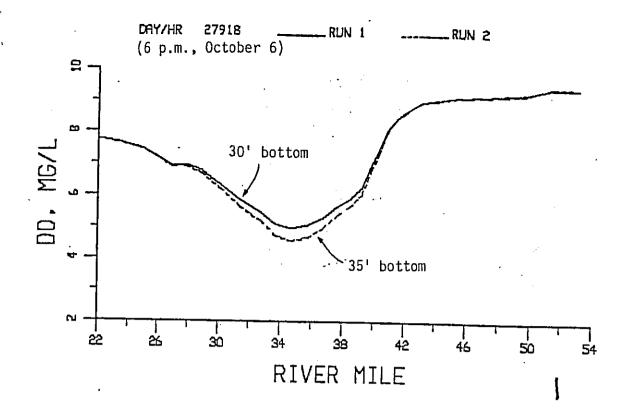
Figure III-1. Computed Oxygen Profiles with 30' and 35'
Channel Bottom Elevations on October 4,
1972
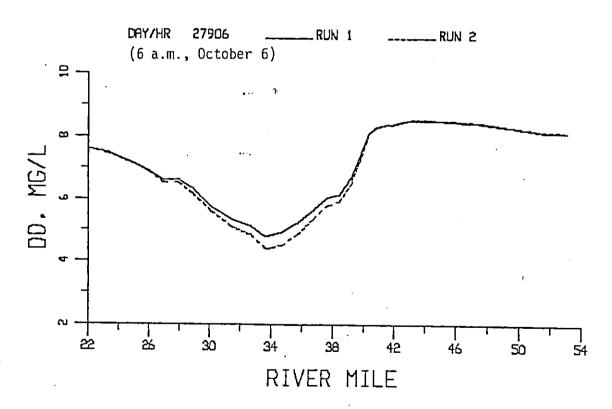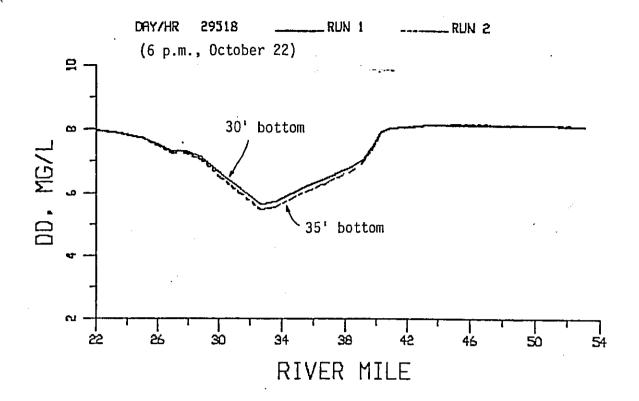
Figure III-2.   Computed Oxygen Profiles with 30' and 35'
Channel Bottom Elevations on October 6,
1978
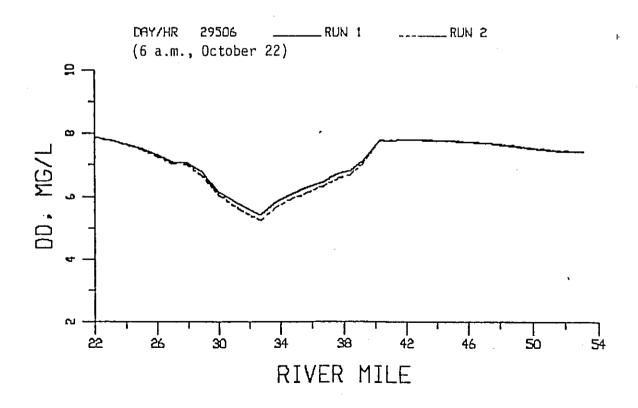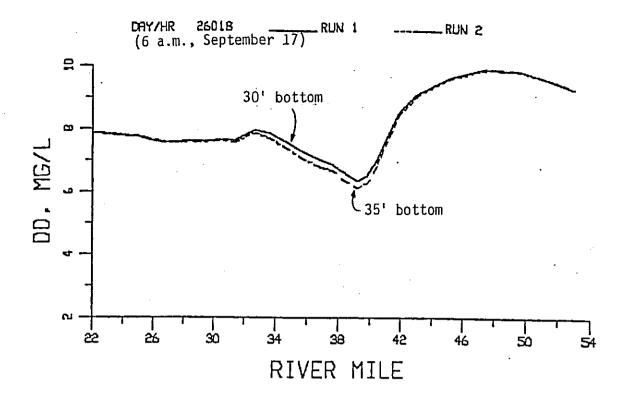
Figure III-3. Computed Oxygen Profiles with 30' and 35' Channel Bottom Elevations on October 22, 1979
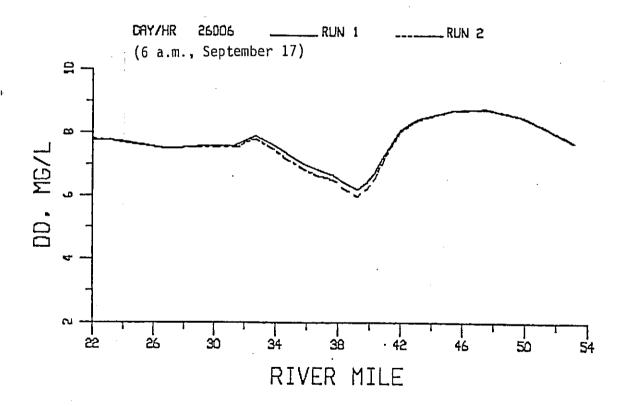
Figure III-4. Computed Oxygen Profiles with 30' and 35' Channel Bottom Elevations on September 17, 1985

deepening was essentially the same. In both cases, the maximum oxygen deficit due to channel deepening was approximately 0.2 mg/l.
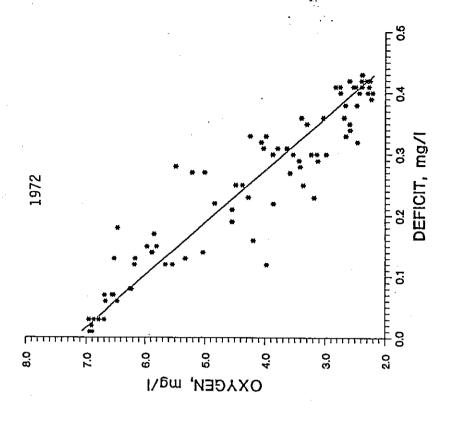
The size of the oxygen deficit due to. channel deepening tends to be proportional to the total oxygen deficit relative to saturation. The proportional decrease in DO results from the greater oxygen demand due to increased depth while reaeration decreases slightly. This relationship is shown on Figures III-5 and III-6. These figures show the computed oxygen deficit due to dredging relative to the computed oxygen level under 30 foot channel bottom elevation conditions during the four simulation periods. Each point on the figures represent a time and location along the ship channel. During 1979, a strong correlation between oxygen level and oxygen deficit is observed. The strong correlation results from the uniform and large net downstream flow condition which prevails throughout the period. The correlation for 1972 is also reasonably good since flows are also reasonably consistent after the barrier was in place. Considerably more scatter is observed for 1978 when flows were more variable and net downstream flows were smaller. During 1985, almost no correlation is observed when many points in time are considered. This scatter conforms to the assumption the large net downstream flow in the San Joaquin River contribute to the good fit observed during the 1979 period. If the deficit is plotted for a single point in time at several locations, the slope of the fit is very similar to the slope observed for the 1979 period. This means that the scatter observed in the 1985 period results from the magnitude of the oxygen concentration responding to environmental changes while the relative effect of channel deepening remains relatively constant.
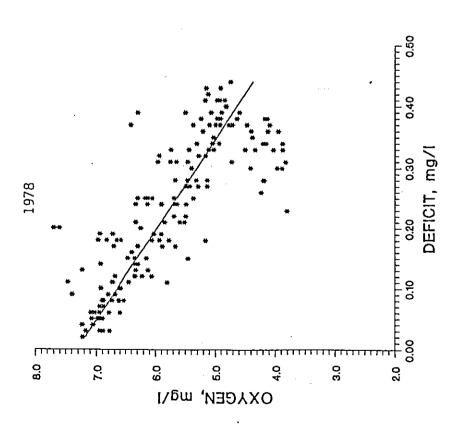
Oxygen Required to Reverse Effects of Channel Deepening

In the previous study, it was estimated that 3400 lbs/day would be required to reverse the effects of increasing the channel depth by five feet. This estimate was based on results for the 1974 and 1978 simulation periods.
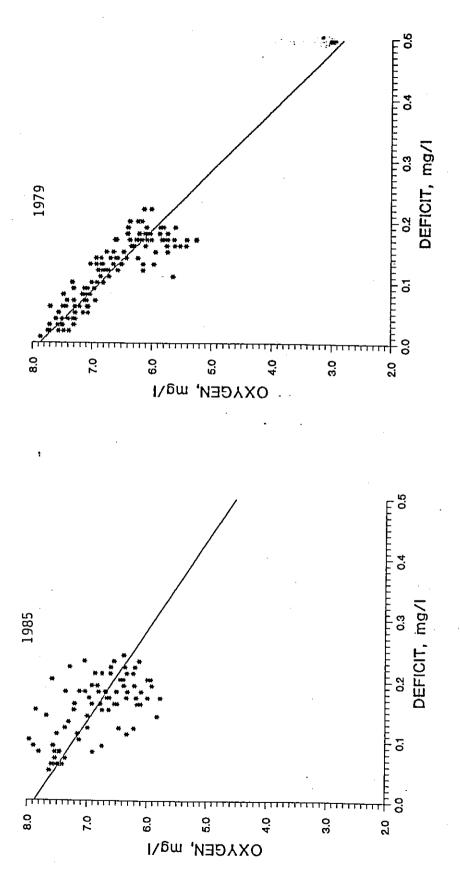
For this study, emphasis was placed on the year which best represented existing conditions (i.e., years since RWWCF upgrade). Two simulation periods were selected for detailed analysis. The 1985 period was selected since it is characteristic of late summer and early fall when the Old River closure is not in place and when oxygen problems may begin to develop in the Ship Channel. The 1979 period was selected to determine how net downstream flow affects the effectiveness and optimal location to implement forced reaeration.
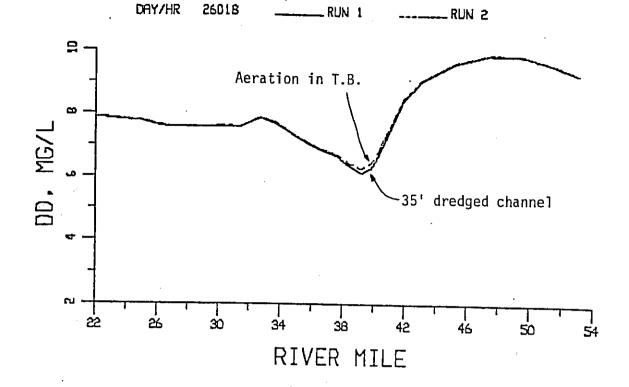
The results of the aeration analysis for the 1985 simulation period are shown in Figures III-7 and III-8. These figures show pairs of computed oxygen concentration profiles for 6 p.m., September 17, 1985. The lower profile of Figure III-7 shows the effects of channel deepening (similar to Figure III-4) and the upper profile shows the effect of adding 850 lbs/day of oxygen to the turning basin (between nodes 28 and 31). Note that the dredged channel profile is dashed in the lower plot and solid in all others. Figure III-7 shows that adding oxygen to the turning basin does little to raise oxygen levels elsewhere in the ship

Figure III-5. Computed Oxygen Deficit Due to Channel Deepening Versus Oxygen Concentration During 1972 and 1978

Figure III-6. Computed Oxygen Deficit Due to Channel Deepening Versus Oxygen Concentration During 1979 and 1985
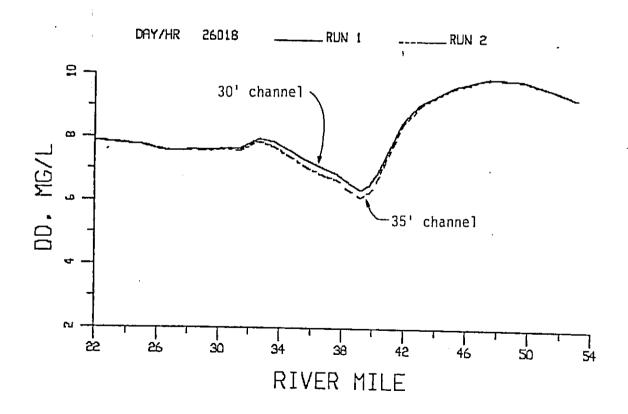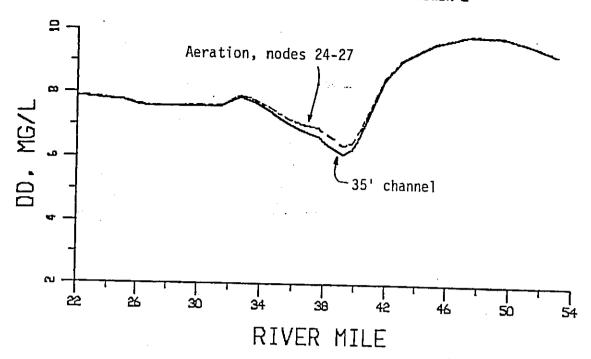
Figure III-7.   Computed Oxygen Concentration Profiles Showing
                Effects of Dredging and Forced Reaeration
                Within the Turning Basin on September 17, 1985

Aeration, nodes 24-27

35' channel

RIVER MILE

Aeration, nodes 26-27

35' channel

RIVER MILE

Figure III-8.   Computed Oxygen Concentration Profiles Showing
Effects of Aeration Between Nodes 24-27 and Nodes 26-27
on September 17, 1985

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channel. Within the turning basin, however, oxygen levels were raised an average of .65 mg/l. The 850 lbs/day does not compensate for channel deepening (e.g., channel deepening lowers oxygen levels by 0.2 mg/l and aeration raised the minimum concentration by 0.15 mg/l). Figure III-8 shows the effects of adding 1250 lbs/day of oxygen to the Ship Channel between nodes 26 and 27 (lower profile) and between 24 and 27 (upper profile).

These profiles show that aeration at the point of minimum oxygen concentration is the most efficient means of increasing the minimum oxygen level within a channel reach. The actual increase in minimum oxygen level was 0.3 and 0.4 mg/l for the nodes 24-27 and nodes 26-27 cases respectively. A comparison of these values with the 0.2 mg/l from the 30 versus 35 foot elevation cases indicates that 625 lbs/day would be required near the point of minimum oxygen concentration or 833 lbs/day over a longer reach to mitigate the effects of channel deepening. Placement of forced aeration at the point of minimum oxygen concentration would also be desirable since most aeration schemes increase in efficiency as the departure from oxygen saturation increases.
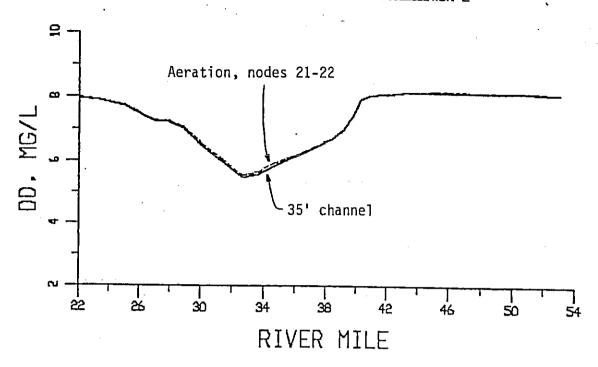
To determine the effects of net flow on the amount of oxygen required to compensate for channel deepening, 1979 conditions were simulated. Figure III-9 shows the effects of 1250 lbs of forced aeration imposed between nodes 24 and 27 and at the point of minimum dissolved oxygen between nodes 21 and 22. Under these high net flow conditions, the forced aeration increased the minimum oxygen concentration by approximately 0.1 mg/l. Under these flow conditions, approximately 2500 lbs/day of oxygen would be required to compensate for channel deepening. The increase in the amount of oxygen required to reverse the deficit is due to the rate at which the oxygen consuming material is replenished by the higher net inflow rate.

Effects of Altered Delta Circulation

Both the observed data and simulation results indicate the dissolved oxygen levels within the Ship Channel are significantly affected by net San Joaquin River flow. At the present time, the DWR and others are considering the possibility of installing flow control devices and modifying channel geometry to affect improved through-Delta transfer of water to the CVP and SWP pumps to evaluate how revised Delta circulation patterns would affect San Joaquin River and Ship Channel water quality. Two simulations were performed using the 1985 simulation period. This period was selected because net flows near Stockton were near zero and the Old River barrier was not in place.

The first simulation evaluated the effects of installing a moveable barrier in the Sacramento River to force more water through the Cross Delta Channel and down the Mokelumne River. This option is being considered to reduce the amount of salt which enters the Delta from the Bay. With the barrier installed, computed net downstream flows in the Mokelumne River increased approximately 1000 cfs. The oxygen levels computed for this case, however, were virtually identical to the no
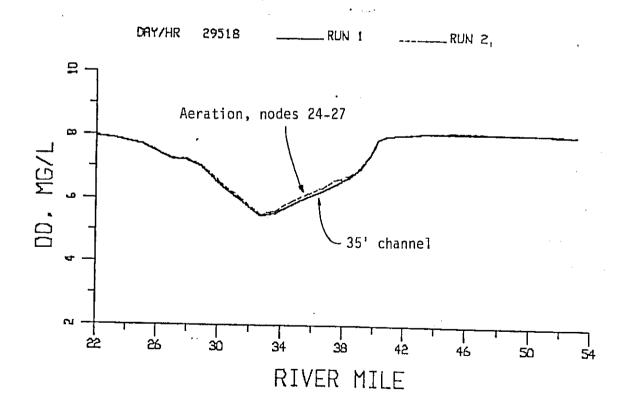
Figure III-9. Computed Oxygen Concentration Profiles Showing
Effects of Aeration Between Nodes 24-27 and
21-22 on October 22, 1979
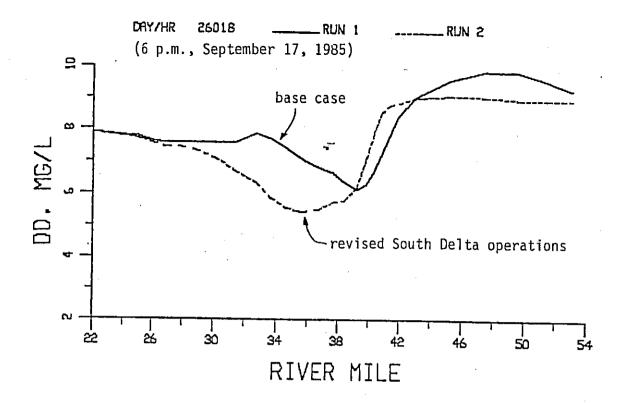
barrier case results. These simulation results indicate that this type of through-Delta transfer plan would have little effect on DO in the Ship Channel and San Joaquin River.

The second simulation evaluated the effects of modifying operation of the Southern Delta. The plan evaluated included a tide gate structure in Grant Line Canal to limit flow from node 141 to 142 and moving the Clifton Court entrance north to node 132. Both of these options are being considered to raise water levels and improve circulation south and east of Clifton Court and lower the rate of salt buildup in the southern Delta. As a result of higher water levels south of Union Island, the net downstream flow in the San Joaquin River would increase. The computed net downstream flow in the San Joaquin River below Old River increased from approximately 200 cfs to approximately 1200 cfs under this plan.
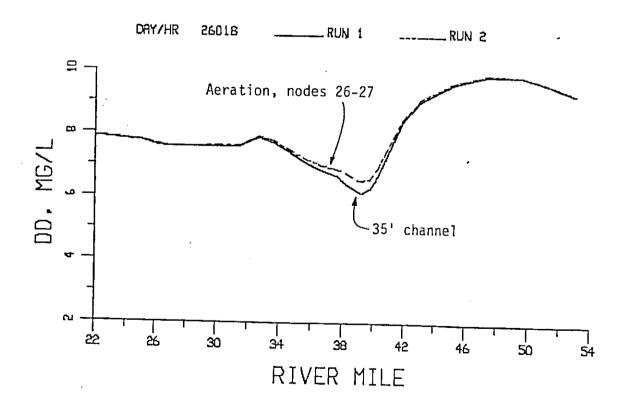
The effects of the increased net downstream flow on computed water quality assuming a 35' bottom is shown in Figure III-10. This figure shows that oxygen levels are depressed and the point of maximum sag is forced further downstream with the increased flow and increased amount of oxygen-consuming materials which enter the Ship Channel from the San Joaquin River.

In the calibration and validation section of this report, the probability exists that direct discharge of oxygen consuming materials to the Ship Channel is underestimated. Larger net downstream flow would tend to flush the pollutants of local origin from the Ship Channel, thereby improving oxygen levels. This beneficial effect is not reflected in the model results since no nonpoint local sources are input to the model. The model simulation results, however, show that there is a potential for adverse quality effects associated with increases in net downstream flow due to upstream oxygen demands. Therefore, this potential should be thoroughly investigated prior to installation or modification of any facility which increases downstream flow in the San Joaquin River.

A third revision to Delta operation involved the installation of tide gates near both ends of Honker Cut. This plan, which is not being considered by any agency, was included only as a demonstration to show effects of increasing inflow to the Ship Channel from Fourteen Mile Slough. By installing tide gates on Disappointment and White Sloughs at the west end of King Island, tidal flows could be limited to an easterly direction (i.e., node 98 to 100 and 99 to 101). This plan was evaluated using the 1979 simulation period. This year was selected since high net downstream flows with their high oxygen-demanding load would be diluted by the Fourteen Mile Slough inflows. The simulation results indicate that such a system would increase net southerly flow into the Ship Channel from 14 mile slough from near zero to approximately 600 cfs. The results of the quality simulation are shown on Figure III-11. The computed oxygen levels are raised significantly by the higher quality water originating from the Sacramento River. Such a system would more than compensate for predicted effects of channel deepening.
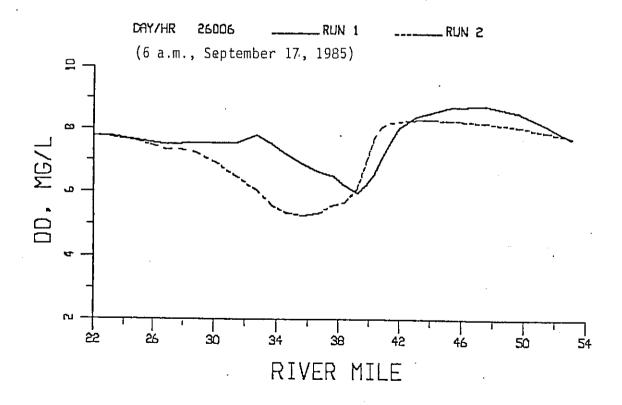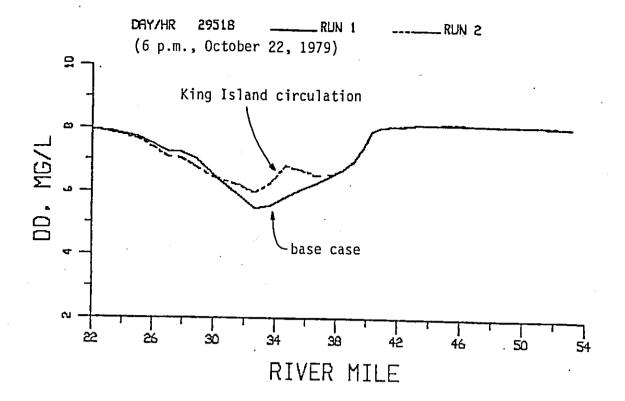
Figure III-10. Computed Oxygen Levels in the Ship Channel and San Joaquin River With and Without Revised South Delta Operation

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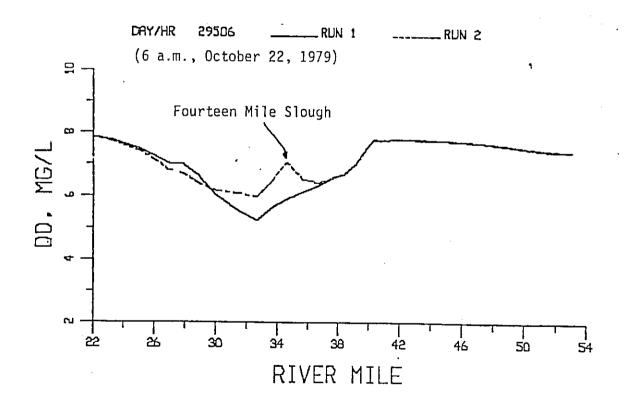
Figure III-11. Computed Oxygen Levels in the Ship Channel and San Joaquin River With and Without the Kings Island Circulation Plan, 1979

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IV. Summary and Recommendations

The results of model validation and calibration demonstrated that the model adequately represents the hydrodynamic and water quality responses of the San Joaquin River, Ship Channel and surrounding Delta under a wide range of hydraulic and inflow conditions. The flow split between the San Joaquin River and Old River, which is a critical factor influencing Ship Channel quality, was well represented. In general, both the magnitude and location of the oxygen sag in the Ship Channel was adequately represented. However, the quality model seems to be less reliable when net flows in the ship channel are near zero. During the 1985 simulation period when net San Joaquin River flows were near zero, the simulated oxygen sag did not extend as far downstream as was observed in the field. Underpredicting the extent of the oxygen sag could be caused by overlooking waste loads which may be discharged to the turning basin and Ship Channel, and by computing less than actual intertidal flows which would carry more oxygen-consuming materials into the Ship Channel.

The evaluation of the effects of channel deepening indicated that a linear relationship exists between oxygen deficit caused by the deeper channel and the magnitude of the oxygen concentration (i.e., the lower the concentration, the larger the deficit). The simulation results indicated that under present RWWCF discharge conditions, the maximum oxygen deficit attributed to channel deepening would be approximately 0.2 mg/l.

The analysis of the location and rate of forced aeration showed that reaeration at the point of minimum oxygen concentration would be the most effective. The analysis also showed the amount of oxygen required to reverse the effects of the deeper ship channel increased as the net ship channel flow rate increases (i.e., as more poor quality San Joaquin River water is forced to flow past Stockton rather than be exported via Old River). The amount of oxygen required to reverse the effects of channel deepening under present conditions ranged from apaproximately 625 lbs/day under near zero net flow to approximately 2500 lbs/day when the net downstream San Joaquin River flow approaches 2000 cfs.

The analysis of proposed Sacramento barrier design to enhance through-Delta transfer of water to the State and Federal pumps indicated such a plan would have no significant effect on water quality in the Ship Channel. Proposed modifications to Southern Delta operations that increase water levels would result in larger net downstream flow in the San Joaquin River. Model results indicate that larger net downstream flows, with their present phytoplankton loads, contribute to lower oxygen levels under some conditions. This conclusion, however, is based on the assumption that no significant wasteloads are discharged to the Ship Channel and turning basin. If significant wasteloads are being discharged, larger net downstream discharges may have a beneficial effect. The analysis of channel modifications which significantly

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increase net flows into the Ship Channel from Fourteen Mile Slough showed that such flows could more than compensate for the oxygen deficit attributed to channel deepening.

Recommendations

Many of the conclusions reached in the two Stockton Ship Channel studies could be altered if significant waste loads are being discharged to the turning basin and Ship Channel. The amount of oxygen consuming material of local origin would have a significant impact on the analysis of the effectiveness of increasing net channel flow to improve water quality in the Ship Channel. Since the observed data seem to indicate that local waste loads may be present, it is recommended that a field program be initiated to identify and measure the oxygen consuming potential of all discharge to the Ship Channel between mile 32 and the end of the turning basin.

The quality simulation results indicate that computed intertidal flow may be less than actual even though tidal stage is reproduced well. To insure the mass transport due to intertidal flow is being properly accounted for, it is recommended a current metering program be initiated if existing data sets cannot be located. As a minimum, tidal currents should be measured over an entire mean tide cycle in the San Joaquin River at Burns Cutoff upstream of the Ship Channel and in the Ship Channel in the vicinity of mile 35.5 (Light 36).

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3. California State Department of Water Resources, Central District, "Dayflow Summary, Water Years 1955 Through 1985," February, 1986.

4. Zison, S. W., et al., "Rates, Constants and Kinetics Formulations in Surface Water Quality Modeling," Tetra Tech, Inc., Technical Report prepared for the Environmental Protection Agency, Athens, Georgia, December, 1978.

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7. 1972, 1974, 1978, 1979, 1981 and 1984 Old River Closure Reports, California State Department of Water Resources.

APPENDIX

1972 SIMULATION PERIOD HYDROLOGY

DATE	S.J.R.	MOK.R.	SAC.R.	S.T.P.	C.C.CO.	C.V.P.	S.W.P.	AG.USE	AG.RET.	S.J.R.D/S
SEP 12, 1972	1540	58	17800	58	208	3960	3145	2510	587	-10
SEP 13, 1972	1650	62	18200	57	208	3940	3109	2467	574	-9
SEP 14, 1972	1800	62	18400	57	212	3940	3073	2424	561	61
SEP 15, 1972	1820	60	18400	56	209	4000	2966	2392	550	76
SEP 16, 1972	1880	54	18300	51	203	3940	3122	2361	539	94
SEP 17, 1972	1980	62	18200	31	206	3960	3100	2329	528	198
SEP 18, 1972	2120	62	17800	55	198	3920	3111	2297	516	294
SEP 19, 1972	2170	53	16900	58	176	3940	3124	2265	505	274
SEP 20, 1972	2180	44	16000	58	188	3900	2704	2234	494	260
SEP 21, 1972	2170	42	16100	57	183	3880	2489	2202	483	254
SEP 22, 1972	2230	40	16100	57	183	3920	2533	2170	472	262
SEP 23, 1972	2240	38	15700	34	171	3910	3145	2139	461	265
SEP 24, 1972	2260	38	16000	34	166	3970	3512	2107	450	293
SEP 25, 1972	2190	38	16000	48	170	3850	3184	2075	439	269
SEP 26, 1972	2050	49	16300	50	163	3920	3081	2044	427	155
SEP 27, 1972	2060	73	16700	42	152	3940	3046	2012	416	1116
SEP 28, 1972	2150	69	17000	35	151	3910	967	1980	405	1350
SEP 29, 1972	2070	62	17200	47	153	3940	1615	1949	394	1376
SEP 30, 1972	1930	59	17000	48	153	3920	3054	1917	383	1318
OCT 1, 1972	1840	58	17000	36	129	3950	3046	1885	372	1245
OCT 2, 1972	1830	58	16800	47	149	3920	3046	1854	361	1196
OCT 3, 1972	2000	58	16500	43	131	3840	2944	1822	350	1222
OCT 4, 1972	2320	57	16100	41	148	3960	3044	1790	339	1417
OCT 5, 1972	2280	58	15800	40	119	3960	2896	1759	327	1535
OCT 6, 1972	2140	56	15300	38	126	3990	2360	1727	316	1429
OCT 7, 1972	2000	48	14900	35	124	3970	3134	1695	305	1214
OCT 8, 1972	1980	47	14900	22	125	4000	3157	1664	294	1225
OCT 9, 1972	1980	47	14900	34	122	3970	3169	1632	283	1233
OCT 10, 1972	1960	46	15000	34	122	3980	2924	1600	272	1218
OCT 11, 1972	1930	117	15900	32	140	3980	3165	1569	261	1259
OCT 12, 1972	1800	114	16100	31	113	4000	3410	1537	250	1145
OCT 13, 1972	1690	101	16400	26	112	4000	2136	1505	238	1046
OCT 14, 1972	1650	102	16600	23	102	3980	3288	1474	227	1070

1974 SIMULATION PERIOD HYDROLOGY

DATE	S.J.R.	MDK.R.	SAC.R.	S.T.P.	C.C.CO.	C.V.P.	S.W.P.	AG.USE	AG.RET.	S.J.R.D/S
SEP 11, 1974	2390	527	27600	53	116	2860	5195	2553	600	315
SEP 12, 1974	2560	532	27600	56	127	2850	2895	2510	587	505
SEP 13, 1974	2500	590	27200	61	126	2880	1805	2467	574	546
SEP 14, 1974	2450	608	27000	56	123	2870	1489	2424	561	533
SEP 15, 1974	2420	614	26600	53	121	2270	1801	2392	550	1039
SEP 16, 1974	2400	628	26500	53	122	2770	2517	2361	539	1050
SEP 17, 1974	2420	599	26500	57	112	3260	1935	2329	528	1694
SEP 18, 1974	2680	604	22650	59	107	3270	1364	2297	516	2246
SEP 19, 1974	3150	605	26000	58	98	3330	1145	2265	505	2570
SEP 20, 1974	3500	644	25200	56	96	3290	873	2234	494	5875
SEP 21, 1974	3630	554	24200	56	95	3300	1194	2202	493	2413
SEP 22, 1974	3620	546	23400	48	94	3290	3434	2170	472	1925
SEP 23, 1974	3650	551	22900	50	94	3280	1098	2139	461	1553
SEP 24, 1974	3480	540	22600	55	93	3260	768	2107	450	1496
SEP 25, 1974	3520	544	22800	56	91	3300	1095	2075	439	1497
SEP 26, 1974	3630	554	22700	59	91	3940	925	2044	427	1497
SEP 27, 1974	3640	562	22100	57	91	3920	816	2012	416	1547
SEP 28, 1974	3670	576	22000	56	74	3980	832	1980	405	1546

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1978 SIMULATION PERIOD HYDROLOGY

DATE	S.J.R.	MOK.R.	SAC.R.	S.T.P.	C.C.CO.	C.V.P.	S.W.P.	AG.USE	AG.RET.	S.J.R. D/S
SEP 26, 1978	3000	886	16300	45	122	3200	1660	2044	427	699
SEP 27, 1978	2970	899	16200	44	121	3190	1264	2012	416	738
SEP 28, 1978	3060	904	16000	45	122	3180	2126	1980	405	714
SEP 29, 1978	3030	924	15800	44	131	3180	2057	1949	394	697
SEP 30, 1978	3080	921	15900	40	130	3190	2706	1917	383	676
OCT 1, 1978	3180	927	15700	40	136	3187	3094	1885	372	694
OCT 2, 1978	3180	943	15500	41	135	1153	0	1854	361	1300
OCT 3, 1978	3200	869	15300	40	129	821	0	1822	350	1456
OCT 4, 1978	4120	842	14900	38	133	820	0	1790	339	1928
OCT 5, 1978	3580	842	14200	38	131	1022	2944	1759	327	1619
OCT 6, 1978	3240	841	14200	38	131	3246	3022	1727	316	740
OCT 7, 1978	3210	779	14000	34	114	3349	3012	1695	305	692
OCT 8, 1978	3240	751	14300	34	110	3269	3008	1664	294	721
OCT 9, 1978	3230	747	13600	42	113	3246	1123	1632	283	718
OCT 10, 1978	3100	729	12600	40	108	3266	1094	1600	272	816
OCT 11, 1978	3130	743		27	112	3255		1569	261	802

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1979 SIMULATION PERIOD HYDROLOGY

DATE	S.J.R.	MOK.R.	SAC.R.	S.T.P.	C.C.CO.	C.V.P.	S.W.P.	AQ.USE	AQ.RET.	S.J.R. D/S
SEP 30, 1979	2440	455	13700	0	157	4353	4810	1949	394	1433
OCT 1, 1979	2440	458	13200	43	163	4378	4595	1917	383	1398
OCT 2, 1979	2240	481	12600	47	164	4411	2990	1885	372	1258
OCT 3, 1979	2530	472	12800	40	164	4381	3483	1854	361	1373
OCT 4, 1979	2520	465	12600	40	169	4374	4435	1822	350	1408
OCT 5, 1979	2720	457	12600	41	164	4427	3685	1790	339	1511
OCT 6, 1979	2550	453	12500	0	163	4390	3756	1759	327	1450
OCT 7, 1979	2550	468	12200	0	161	4412	4156	1727	316	1432
OCT 8, 1979	2630	520	12900	0	163	4378	3733	1695	305	1490
OCT 9, 1979	2530	519	12700	50	164	4393	3294	1664	294	1455
OCT 10, 1979	2660	508	12500	40	169	4421	3566	1632	283	1513
OCT 11, 1979	2980	512	12300	40	159	4396	2172	1600	272	1693
OCT 12, 1979	3080	509	12800	32	163	4382	1614	1569	261	1809
OCT 13, 1979	2970	515	12900	0	146	4191	3487	1537	250	1765
OCT 14, 1979	3050	515	12900	0	132	3889	4663	1505	238	1798
OCT 15, 1979	3140	518	12200	40	136	4131	3149	1474	227	1858
OCT 16, 1979	3430	514	11000	42	147	4269	2497	1453	222	2008
OCT 17, 1979	4030	514	10600	40	165	3765	2698	1433	216	2307
OCT 18, 1979	3780	515	10100	30	174	3774	4074	1413	211	2281
OCT 19, 1979	3120	569	10100	22	166	3779	3750	1393	205	1854
OCT 20, 1979	3080	569	10500	0	153	3476	4039	1373	200	1756
OCT 21, 1979	3120	574	11200	0	149	3331	4483	1353	194	1827
OCT 22, 1979	2810	562	11300	0	154	3303	3741	1333	188	1683
OCT 23, 1979	2240	544	11500	0	152	3317	2898	1313	183	1362
OCT 24, 1979	2540	543	10500	0	145	3311	4710	1292	177	1388

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1981 SIMULATION PERIOD HYDROLOGY

DATE	S.J.R.	MOK.R.	SAC.R.	S.T.P.	C.C.CO.	C.V.P.	S.W.P.	AG. USE	AG. RET.	S.J.R. D/S
OCT 1, 1981	1140	40	11300	0	167	3224	4194	1917	383	-117
OCT 2, 1981	1230	36	10400	25	166	3159	3599	1885	372	-66
OCT 3, 1981	1370	42	10100	22	159	3300	2892	1854	361	8
OCT 4, 1981	1730	51	9840	23	160	3303	2995	1822	350	139
OCT 5, 1981	1670	62	10200	24	166	3312	3092	1790	339	125
OCT 6, 1981	1400	61	9890	30	153	2916	3290	1759	327	68
OCT 7, 1981	1340	47	10700	38	147	2556	3492	1727	316	78
OCT 8, 1981	1400	35	11100	38	145	2550	3795	1695	305	99
OCT 9, 1981	1500	36	11400	39	149	2556	3891	1664	294	125
OCT 10, 1981	1510	44	10900	47	142	2547	4759	1632	283	79
OCT 11, 1981	1720	44	10600	46	136	2555	4800	1600	272	154
OCT 12, 1981	1780	45	10600	22	139	2531	4700	1569	261	193
OCT 13, 1981	1690	45	10500	36	149	2526	3671	1537	250	182
OCT 14, 1981	1550	45	10700	39	150	2070	3599	1505	238	189
OCT 15, 1981	1670	45	9620	38	158	1738	3672	1474	227	880
OCT 16, 1981	1740	45	9300	36	152	1751	3771	1453	222	1132
OCT 17, 1981	1630	48	9200	52	144	1755	3000	1433	216	1086
OCT 18, 1981	1540	59	8820	52	143	1740	4350	1413	211	1030
OCT 19, 1981	1360	44	9010	19	150	1745	4200	1393	205	923
OCT 20, 1981	1230	43	9080	19	160	1749	3892	1373	200	901
OCT 21, 1981	1100	43	9100	36	136	1672	3600	1353	194	813
OCT 22, 1981	1060	43	8820	39	143	1796	3500	1333	188	760
OCT 23, 1981	1070	43	8440	40	144	1794	3293	1313	183	699
OCT 24, 1981	1060	43	8140	52	140	1799	3500	1292	177	653

1984 SIMULATION PERIOD HYDROLOGY

DATE	S.J.R.	MOK.R.	SAC.R.	S.T.P.	C.C.CO.	C.V.P.	S.W.P.	AG.USE	AG.RET.	S.J.R.D/S
SEP 1, 1984	2590	512	18000	49	216	4002	2469	3028	745	421
SEP 2, 1984	2660	514	18300	51	214	4011	3625	2985	732	404
SEP 3, 1984	2660	524	18700	38	186	3522	2782	2941	719	480
SEP 4, 1984	2660	527	18600	38	195	3345	3015	2898	706	523
SEP 5, 1984	2680	488	18200	38	176	3726	2147	2855	693	529
SEP 6, 1984	2710	518	17500	39	191	3975	2137	2812	680	529
SEP 7, 1984	2780	516	17600	58	191	3945	2117	2769	666	545
SEP 8, 1984	2750	523	18500	58	187	3508	2331	2726	653	1615
SEP 9, 1984	2680	542	18700	19	186	3144	583	2683	640	1795
SEP 10, 1984	2800	543	17600	55	195	3166	2264	2640	627	1767
SEP 11, 1984	2810	542	17800	58	186	3174	1787	2596	614	1828
SEP 12, 1984	2830	537	18300	57	187	3136	2255	2553	600	1899
SEP 13, 1984	2890	533	18800	58	187	3149	1374	2510	587	1916
SEP 14, 1984	2870	506	18800	52	178	3152	3015	2467	574	1901
SEP 15, 1984	2820	511	18800	58	177	3138	2467	2424	561	1877
SEP 16, 1984	2910	539	18800	58	178	3113	3274	2392	550	1986
SEP 17, 1984	3040	559	18800	56	192	3089	1435	2361	539	2044
SEP 18, 1984	3030	568	18100	59	194	2646	2416	2329	528	2063
SEP 19, 1984	2940	575	18700	31	194	2335	2147	2297	516	2040
SEP 20, 1984	2970	585	19400	60	182	2340	2337	2265	505	2101
SEP 21, 1984	3040	584	19800	56	182	2324	1481	2234	494	2129
SEP 22, 1984	3090	587	19800	59	177	2356	2135	2202	483	2124
SEP 23, 1984	3180	593	18800	56	179	2339	2086	2170	472	2140
SEP 24, 1984	3220	607	18100	57	187	2341	1842	2139	461	2205
SEP 25, 1984	3200	608	17300	30	178	2822	1903	2107	450	2207
SEP 26, 1984	3190	617	15700	0	175	3152	1733	2075	439	2177
SEP 27, 1984	3140	588	14700	57	177	3150	1680	2044	427	2165
SEP 28, 1984	3100	578	14600	60	174	3149	1926	2012	416	2128
SEP 29, 1984	3090	576	14300	58	166	3154	1820	1980	405	2112
SEP 30, 1984	3180	585	14000	30	165	3151	3228	1949	394	2124
OCT 1, 1984	3890	623	14500	0	172	3154	2031	1917	383	2655
OCT 2, 1984	3730	538	15800	0	174	3153	1693	1885	372	2673
OCT 3, 1984	3670	488	15700	13	173	3159	1335	1854	361	2655
OCT 4, 1984	3720	511	15200	37	161	3155	1496	1822	350	2652
OCT 5, 1984	3810	545	14500	39	162	3156	1358	1790	339	2698
OCT 6, 1984	3940	561	14000	38	160	3153	1262	1759	327	2779
OCT 7, 1984	4080	549	13800	44	158	3128	1551	1727	316	2874

DATE	S.J.R.	MOK.R.	SAC.R.	S.T.P.	C.C.CO.	C.V.P.	S.W.P.	AG.USE	AG.RET.	S.J.R.D/S
SEP 2, 1985	1990	70	12700	62	211	4286	4784	2985	732	32
SEP 3, 1985	1900	68	13000	53	199	4278	4940	2941	719	-6
SEP 4, 1985	1890	40	12500	51	192	4217	6077	2898	706	-43
SEP 5, 1985	1760	47	12900	56	191	4256	5427	2855	693	-65
SEP 6, 1985	1780	71	12100	52	181	4259	5313	2812	680	-43
SEP 7, 1985	1800	72	12300	58	185	4256	4433	2769	666	1
SEP 8, 1985	1970	99	12600	59	179	4279	3043	2726	653	123
SEP 9, 1985	2170	140	13600	58	173	4240	4256	2683	640	159
SEP 10, 1985	2160	140	14600	59	172	4238	4691	2640	627	144
SEP 11, 1985	2090	135	15300	43	162	4196	5726	2596	614	101
SEP 12, 1985	1960	141	16000	51	158	4208	6459	2553	600	40
SEP 13, 1985	1950	132	15000	60	159	4178	6458	2510	587	-19
SEP 14, 1985	1880	93	14100	60	158	4068	6534	2467	574	-31
SEP 15, 1985	1930	80	13500	61	162	4074	5965	2424	561	-43
SEP 16, 1985	1940	85	12600	57	160	4060	5262	2392	550	27
SEP 17, 1985	1830	98	11900	61	166	3997	4761	2361	539	25
SEP 18, 1985	1780	109	12300	61	170	3857	4274	2329	528	50
SEP 19, 1985	1710	97	11900	59	171	3950	4781	2297	516	-7
SEP 20, 1985	1850	83	11100	57	173	3974	4085	2265	505	15
SEP 21, 1985	1900	85	10700	46	172	3999	3573	2234	494	89
SEP 22, 1985	1900	86	10800	37	166	3979	3084	2202	483	138
SEP 23, 1985	1840	76	10600	37	178	3993	2988	2170	472	152
SEP 24, 1985	1840	44	10500	39	179	3992	3185	2139	461	151
SEP 25, 1985	1850	30	9990	37	177	3984	2987	2107	450	126
SEP 26, 1985	1880	63	9380	38	169	4001	2888	2075	439	104
SEP 27, 1985	1900	76	9790	38	167	3982	2181	2044	427	167
SEP 28, 1985	2030	83	10500	38	162	3952	2985	2012	416	162
SEP 29, 1985	2040	83	10400	37	163	3939	3480	1980	405	174
SEP 30, 1985		72	10900	0	163	3926	3863	1949	394	166